Synergizing fertilizer micro-dosing and indigenous vegetable production to enhance food and economic security of West African farmers
(CIFSRF Phase 2)

Project Number 107983
Location of Study: Nigeria and Benin Republic

"Advanced tools for Food Security Research: Web-based GIS mapping and synchrotron-based analysis for scaling up the MicroVeg agronomic innovations"

By

[1]Peak, D; [1]Minielly, C; [1]Zeng, W; [1] Procyshen, T; [2]Akponikpe, P.B.I; [3]Oyedele, D.J.; [4]Adebooye O.C.
[1]University of Saskatchewan, Saskatoon, Canada
[2]Université de Parakou, Parakou, Benin Republic
[3]Obafemi Awolowo University, Ile-Ife, Nigeria,
[4]Osun State University, Osogbo, Nigeria

Draft 1; March 19 2018

Affaires étrangères, Commerce et Développement Canada
Foreign Affairs, Trade and Development Canada
IDRC | CRDI
International Development Research Centre
Centre de recherches pour le développement international
Canada

Key Messages from this report:

- Our project has taken MicroVeg agronomic research results and linked it with climate and soil data using cutting-edge GIS tools.
- We have produced an online version of our GIS database to publish our project's results across the region. Additionally, we have produced some print-quality maps that are downloadable from our website that can be found at: https://groups.usask.ca/microveg/downloadable-maps.php
- We developed a profit calculator to estimate fertilizer and water needs for any site in Benin Republic and Nigeria using our project's results and a logic model we developed. These data can be exported to a profit calculator that we coded to take all the MicroVeg data for a given spot, and calculate the profit associated with using the MicroVeg agronomic package. Currently, USD, CAD, Euro are enabled but we are working on a script to convert to NGN for Nigeria and CFA for Benin.
- We performed synchrotron-based research on sustainability of MicroVeg technology using the Canadian Light Source (CLS) and used the results to infer the sustainability of MicroVeg practices on soil health.
  - We found that the forms of carbon (C) depend upon ecoregion rather than the vegetable choice or fertilization, implying that this element is not strongly affected by MicroVeg over the time frame of this project.
  - We found that the forms of soil nitrogen (N) are strongly influenced by the MicroVeg inorganic fertilizer input. We observe decreased total N levels in MicroVeg plots compared to manure-only samples, but the organic forms of soil N had shifted from decomposed forms into more protein-rich forms. This suggests that MicroVeg additions are increasing plant biomass and yields, and inorganic N is cycling and will be available in the seedbed.
  - We found that Phosphorus (P) had some initial dependence on ecoregion, with soils from the Sudano-Savannah being higher in calcium phosphate before planting. However, the major changes in available P are due to a combination of N fertilizer addition and the choice of vegetable. These results suggest that later harvests of *Amaranthus* could benefit from a side-dress NPK application.
- From the totality of our soil nutrient and synchrotron analyses, we conclude that MicroVeg is a beneficial innovation for resource limited rural farmers to increase yields and fertilizer efficiency.

I: WebGIS:

As our online tools became more elaborate, we developed a parent website at www.microveg.ca to house the information. As previously reported, we have successfully produced a Web-based GIS system that allows one to visualize GIS data compiled from online sources as well as our project's research. It can still be found at:

http://webgis.usask.ca/microveg/

The WebGIS system was delivered in beta form at AfriVeg 2017 conference in Cotonou Benin, and suggestions from surveys and hands-on testing by researchers and NGOs was incorporated into the current and final version. The major changes to the tools were focused on the Profit Calculator, where we added local currencies (CFA and NGN), simplified the interface considerably, and cleaned up some of the code from its initial version. The web sites were also redesigned to be more readable on mobile devices.

We have also completed (and uploaded) a User Guide for both the WebGIS and the profit calculator. This user guide contains many images of both the online mapping system and the profit calculator, and can be found here:

http://webgis.usask.ca/microveg/UserManual.pdf

To provide some more highlights of our web-based GIS system, we repeat the summary from our September 2017 report where the website was first launched, with additions and updates as necessary.

The WebGIS platform contains all the layers of climate, topographical, infrastructure, and soil data that were collected and compiled from open sources and reformatted for cross compatibility. Additionally, the WebGIS also contains all the MicroVeg project's agronomic data. These data were adjusted into two seasons (wet vs. dry) three ecozones (rainforest, savannah, and sudano savannah) for the four vegetable crops of the project. This allows us to provide an estimated vegetable yield, water requirements, and microdose fertilizer rate for any location in Benin Republic or Nigeria.

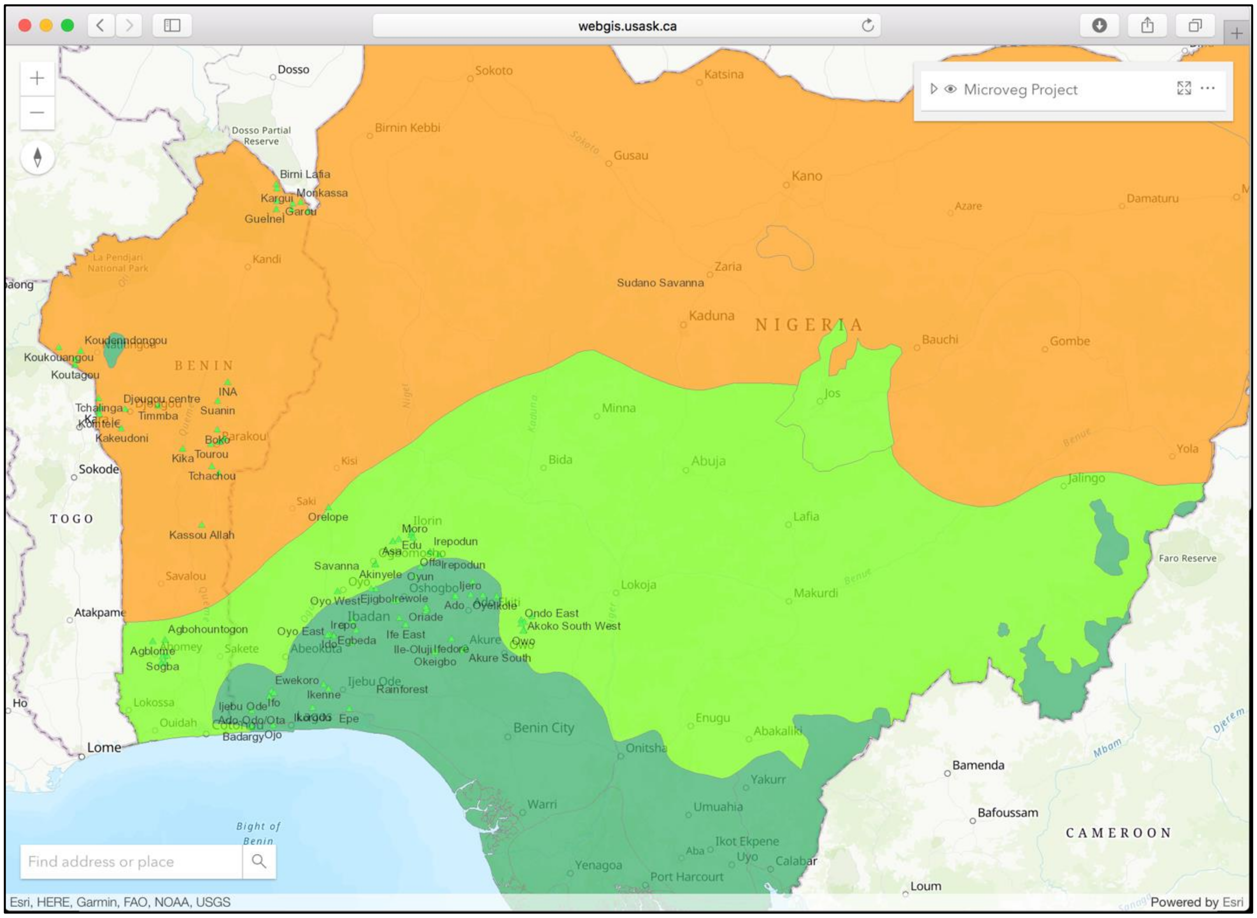


Figure 1: Initial WebGIS interface showing ecoregions (as defined by the project) and research sites.

As an example of this, Figure 2 shows how the combination of seasonal climate (temperature, elevation, precipitation) and research project-based water requirements for indigenous vegetables are used to calculate irrigation needs for amaranth (as well as the region where amaranth production can easily be scaled up based upon climate).

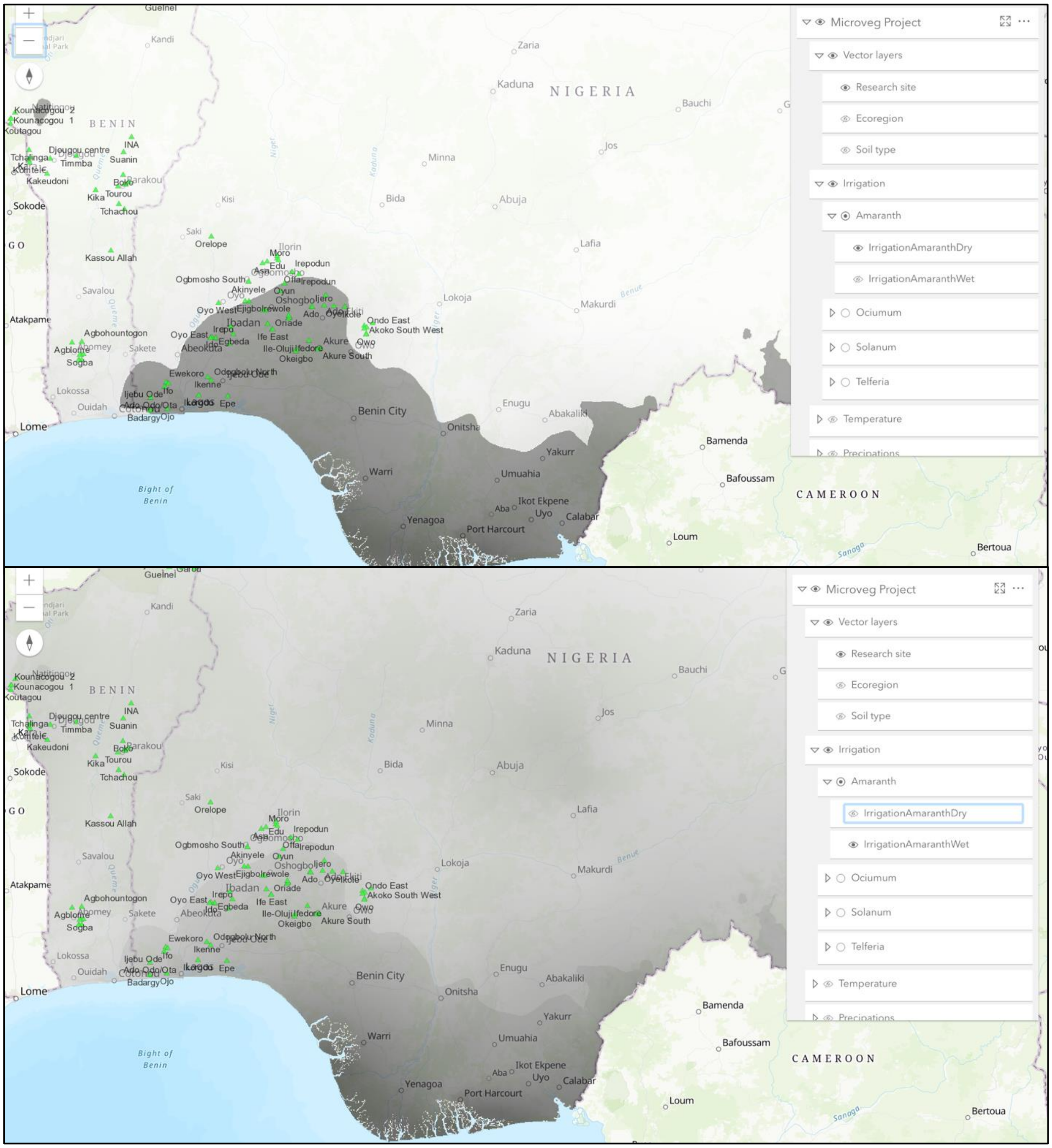
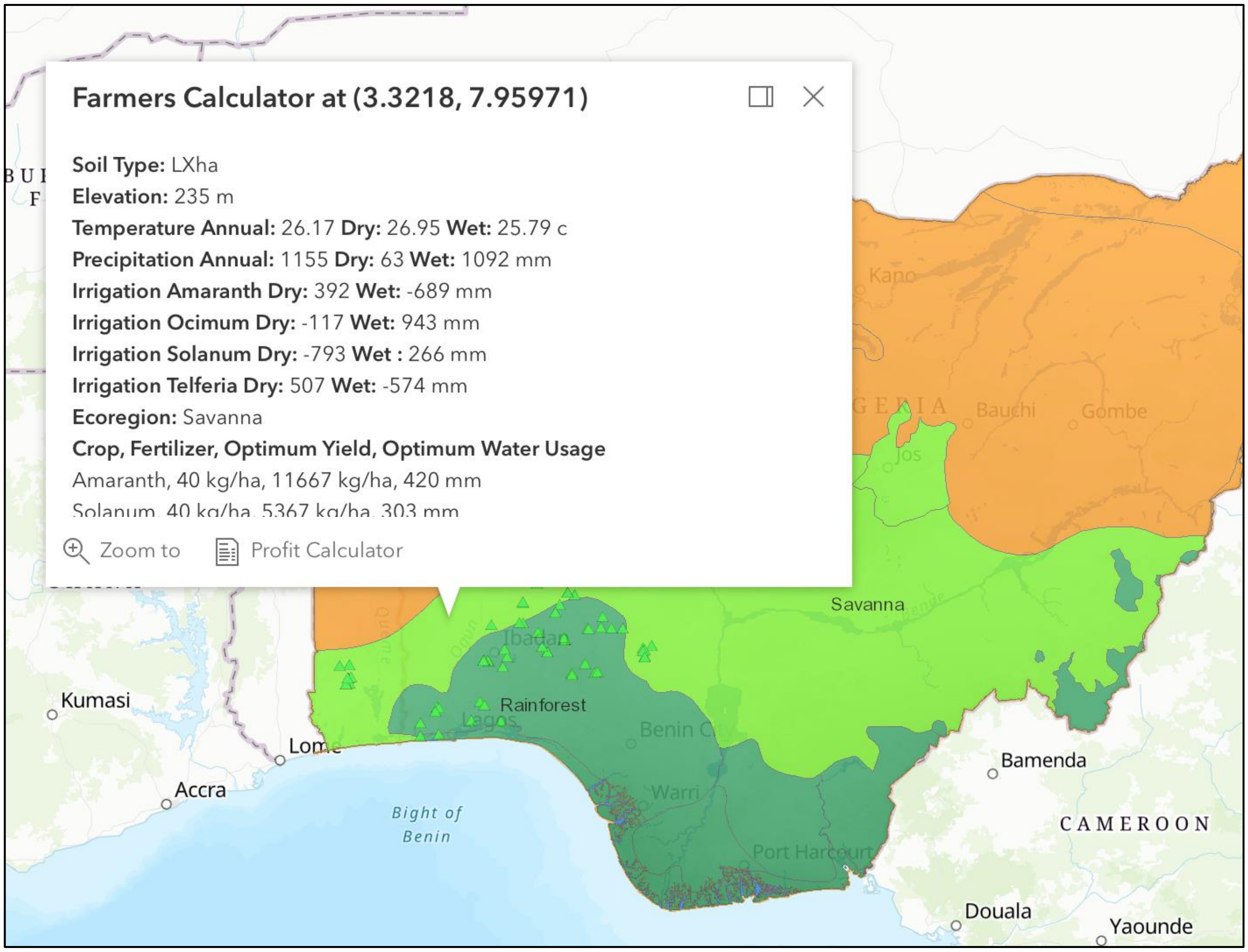


Figure 2: Irrigated water demands of amaranth in the dry season (top) and rainy season (bottom). Areas not in greyscale are not suitable for amaranth production based upon other climatic variables.

In addition to this visual way of compiling data, there is also the ability to query the website's spatial information throughout the layers of WebGIS for a given location.



Farmers Calculator at (3.3218, 7.95971)

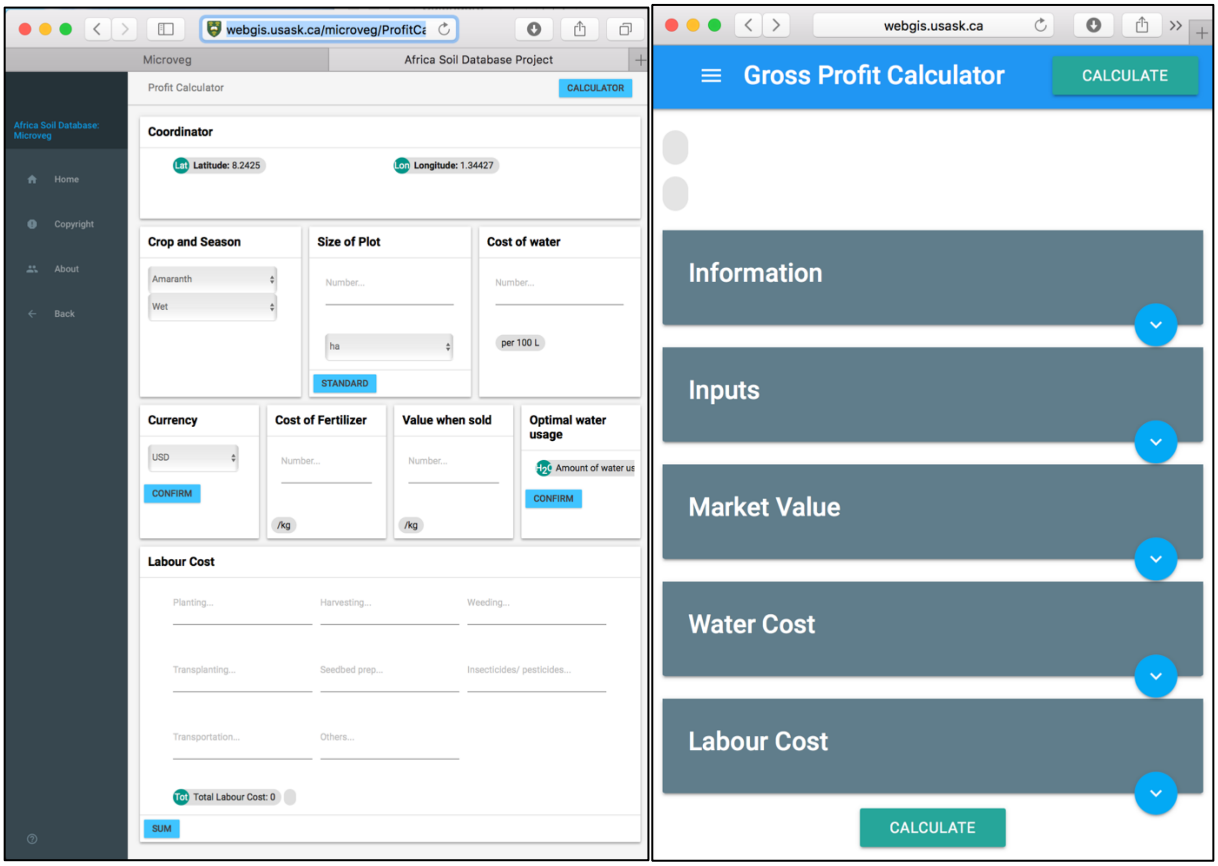
Soil Type: LXha
Elevation: 235 m
Temperature Annual: 26.17 **Dry:** 26.95 **Wet:** 25.79 c
Precipitation Annual: 1155 **Dry:** 63 **Wet:** 1092 mm
Irrigation Amaranth Dry: 392 **Wet:** -689 mm
Irrigation Ocimum Dry: -117 **Wet:** 943 mm
Irrigation Solanum Dry: -793 **Wet :** 266 mm
Irrigation Telferia Dry: 507 **Wet:** -574 mm
Ecoregion: Savanna
Crop, Fertilizer, Optimum Yield, Optimum Water Usage
Amaranth, 40 kg/ha, 11667 kg/ha, 420 mm
Solanum, 40 kg/ha, 5367 kg/ha, 303 mm

Figure 3: Quantitative data for a location in the study zone obtained by left click of the cursor in WebGIS. Note the profit calculator button at bottom.

This provides access to quantitative data, but more importantly it can be exported to a profit calculator that we coded to take all the MicroVeg data for a given spot, and calculate the profit associated with using the MicroVeg agronomic package. Currently, USD, CAD, Euro are enabled but we are working on a script to convert to NGN for Nigeria and CFA for Benin. Expected yields, water requirements, and optimal microdose fertilizer rate are provided by WebGIS, and farmers/NGO/extension agents can input the vegetable to be grown, size of vegetable plot, cost of fertilizer, value of vegetables per unit, and labor costs for production. It is also possible to access the calculator directly at:

http://webgis.usask.ca/microveg/ProfitCalculator.html

The profit calculator then estimates the profitability of the MicroVeg platform for that farmer. The interface is still being revised, but an example of the current implementation of the profit calculator is available in Figure 4.



Latitude: 8.2425
Longitude: 1.34427
Amaranth
Wet
ha
USD
Total Labour Cost: 0

Figure 4: (left) beta version and (right) final version of a profit calculator for the location defined in Figure 3. It is possible to compare profits for different crops based upon common inputs, or to estimate the profitability of production using the MicroVeg technique compared to current practices.

This web-based GIS system is similar in concept and function to the technology that agronomists use in western Canada, but is open-source, specific to the MicroVeg project, and optimized for use on slower internet connections. This WebGIS implementation allows us to scale up our MicroVeg agronomic package by extrapolating our project's site-specific research data to the region in a rational manner.

Additionally, we have produced some print-quality maps that are downloadable from our website that can be found at: https://groups.usask.ca/microveg/downloadable-maps.php

II. Linking Field Research on the Sustainability of MicroVeg with Synchrotron Activities

In spring 2017, two UofS graduate students conducted a 2 week field program to visit research sites in Benin Republic and Nigeria. The objectives of this visit were (1) to survey farmers participating in the MicroVeg project and compare their profits with the profits of research trials as well as farmers who grew vegetables outside of MicroVeg project (2) to establish the ecosystem functions of soils in vegetable plots under MicroVeg management.

We evaluated the success of both these subprojects with a combination of wet chemistry, surveys, and CLS-based analysis of the soil samples shipped from west Africa. We have performed basic analysis (pH, CEC, OC, total and available N and P) on approximately 1000 samples and used those chemical analyses as a way to screen synchrotron analyses on ~25 samples per study to determine the changes in chemical speciation of soil C, N, and P using the Canadian Light Source. One manuscript about P speciation changes in MicroVeg research plots is currently in internal revision for submission in April 2018, and a second manuscript that compares the performance of MicroVeg on experimental research sites, on MicroVeg farmer plots, and on similar plots of vegetable producers not using MicroVeg has been submitted to a special issue of Journal of Environmental Quality on Food Security and Soil Health. The results of the synchrotron-based portions of these two papers are summarized below.

1) Phosphorus chemistry in west African soils employing MicroVeg Innovation. For this study, two research sites were sampled, in Ilesha, Nigeria (rainforest ecozone) and Ina Benin (dry savanna). Samples were collected either before planting or after the harvest, and on sites where either *Amaranthus* or *Solanum* was cultivated. Results of analysis for the Ilesha site are shown in Figure 5 below.

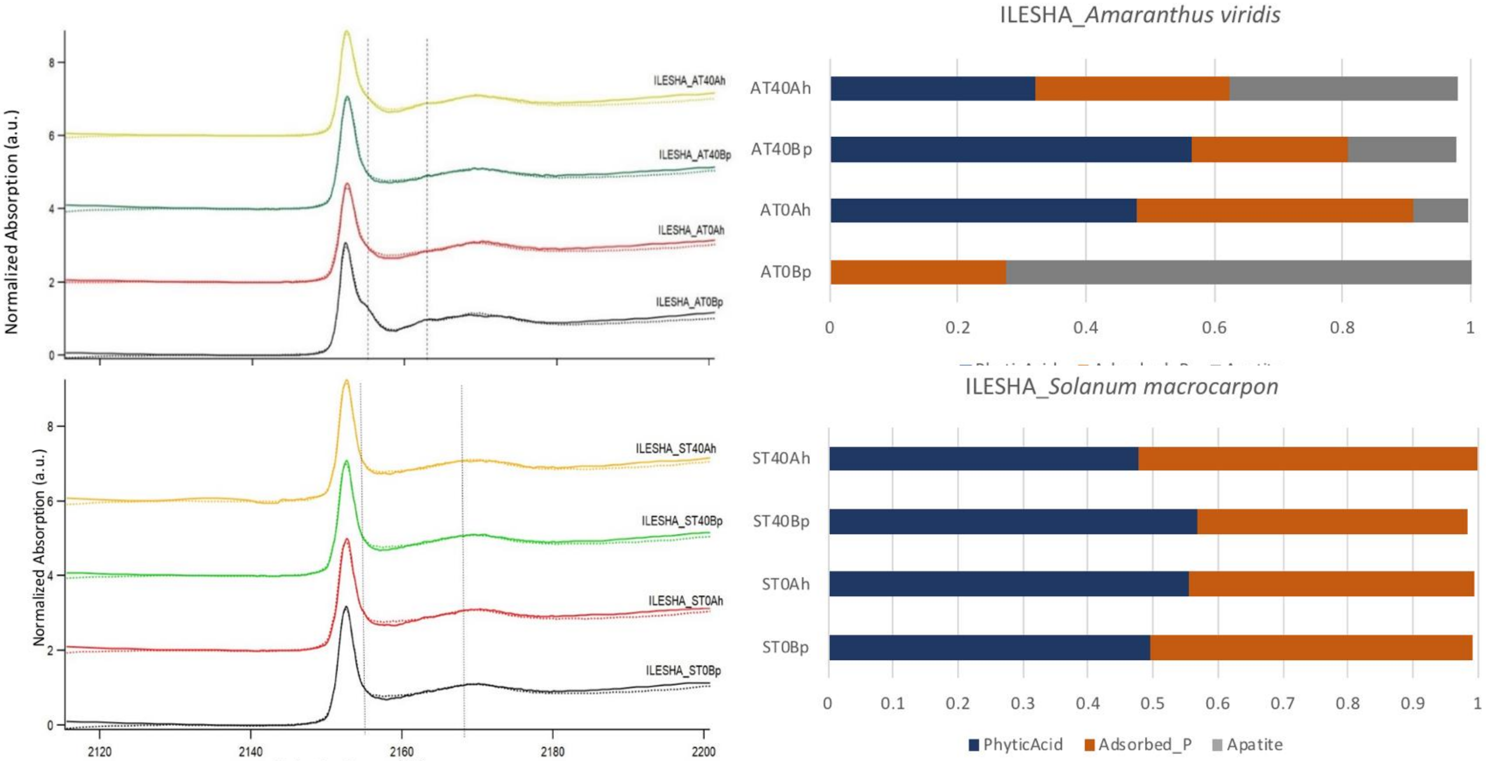


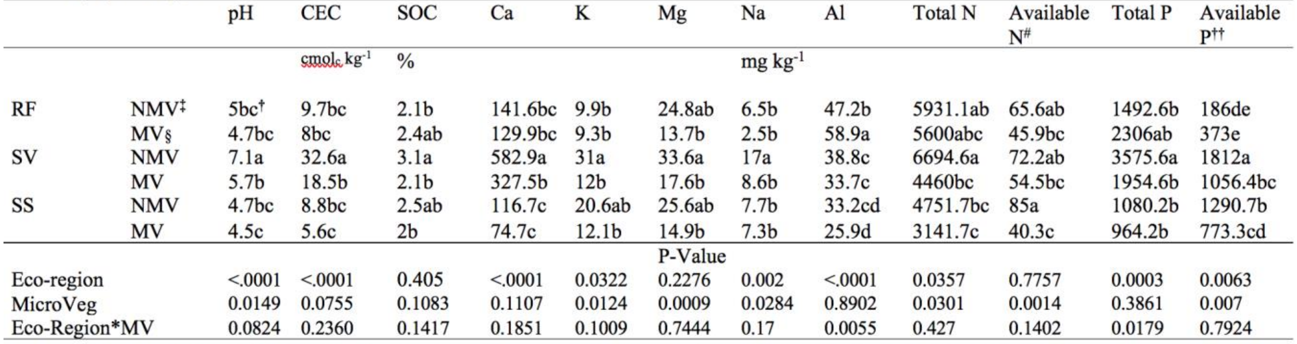
Figure 5: Normalized P K-edge X-ray Absorption Near Edge Structure (XANES) spectra showing the Linear Combination Fitting (LCF) results of Ilesha soils cultivated with either *Amaranthus viridis (*top row) or *Solanum macrocarpon* (bottom row) amended with poultry manure alone (**T0**), and that amended with poutry manure and 40 kg N/ha of Urea (**T40**). ***Bp*** means before planting, ***Ah*** means after harvest.

The quantitative analysis of the XANES spectra of the Ina soils of Benin Republic under cultivation by both the local amaranth (*Amaranthus viridis*) and the African eggplant (*Solanum macrocarpon*) showed that adsorbed P and phytic P were the two dominant P species in the manure amended soils before and after planting. The urea-fertilized soils showed a dominance of adsorbed P before planting, and then a rapid microbial immobilization that shifts the P speciation to phytic P (organic P) in the soils cultivated with *Amaranthus viridis*. Interestingly, the soils cultivated with the African eggplant (*Solanum macrocarpon*) showed no shift in the ratio of adsorbed P and phytic P. In contrast with Ina samples, the XANES analysis of the Ilesha soils had relatively high initial amounts of apatite P in the manure amended soils cultivated with *Amaranthus viridis* prior to planting. This apatite P was absent in the after-harvest samples, suggesting it is being transformed and converted to both adsorbed and phytic P. When urea is added to this same soil, XANES analysis showed a shift in the dominant P species from phytic P before planting to adsorbed P and apatite P most likely through a combination of rapid mineralization and precipitation process. This may potentially immobilize some of that P, as apatite is much less soluble and is considered less available.

2) C and N Speciation in indigenous vegetable plots of Nigeria and Benin. Soil samples and yield data from farms implementing (MV) and not implementing MicroVeg (NMV) recommendations for production of the tete indigenous vegetable were taken from three eco-regions of Nigeria and Benin and compared using soil chemical analysis and X-ray absorption near edge structure (XANES) spectroscopies at the C and N K-edges.

Results from soil chemical analysis for pH, SOC, CEC, available and total N and P, and base cations are shown in Table 1.

Table 1. Soil chemical analysis of MicroVeg and Non MicroVeg soils for the Rainforest (RF), Savanna (SV), and Sudano Savanna (SS) eco-regions.



		pH	CEC	SOC	Ca	K	Mg	Na	Al	Total N	Available N[#]	Total P	Available P[††]
			cmolc kg^{-1}	%				mg kg^{-1}					
RF	NMV[‡]	5bc[†]	9.7bc	2.1b	141.6bc	9.9b	24.8ab	6.5b	47.2b	5931.1ab	65.6ab	1492.6b	186de
	MV[§]	4.7bc	8bc	2.4ab	129.9bc	9.3b	13.7b	2.5b	58.9a	5600abc	45.9bc	2306ab	373e
SV	NMV	7.1a	32.6a	3.1a	582.9a	31a	33.6a	17a	38.8c	6694.6a	72.2ab	3575.6a	1812a
	MV	5.7b	18.5b	2.1b	327.5b	12b	17.6b	8.6b	33.7c	4460bc	54.5bc	1954.6b	1056.4bc
SS	NMV	4.7bc	8.8bc	2.5ab	116.7c	20.6ab	25.6ab	7.7b	33.2cd	4751.7bc	85a	1080.2b	1290.7b
	MV	4.5c	5.6c	2b	74.7c	12.1b	14.9b	7.3b	25.9d	3141.7c	40.3c	964.2b	773.3cd
							P-Value						
Eco-region		<.0001	<.0001	0.405	<.0001	0.0322	0.2276	0.002	<.0001	0.0357	0.7757	0.0003	0.0063
MicroVeg		0.0149	0.0755	0.1083	0.1107	0.0124	0.0009	0.0284	0.8902	0.0301	0.0014	0.3861	0.007
Eco-Region*MV		0.0824	0.2360	0.1417	0.1851	0.1009	0.7444	0.17	0.0055	0.427	0.1402	0.0179	0.7924

†Means within a column followed by the same letter are not significantly different ($p \geq 0.05$) using Tukey test for LSD

‡ Non MicroVeg

§ MicroVeg

Available Nitrogen in the form of NO_3^-

†† Available Phosphorus in the form of PO_4^{-2}

A significant difference in soil properties was found primarily in the SV eco-region, where nutrient levels were significantly higher in NMV soils. The pronounced difference in soil fertility was likely a result of texture rather than management practices as NMV soils were dominated by clay and silt (60%) while MV soils were dominated by sand (70%). Results obtained from the SV eco-region were similar to previous research that reported soils higher in clay content displayed higher OC and nutrient levels. In the RF eco-region, SOC levels were higher in MV soils where clay and silt content were also higher (58 compared to 44%), further strengthening the notion that OC content in our study was influenced more strongly by eco-region rather than management practices.

XANES analysis was used to determine quantitatively the chemical forms and overall quantity of soil C and N, as shown in Figure 6 below.

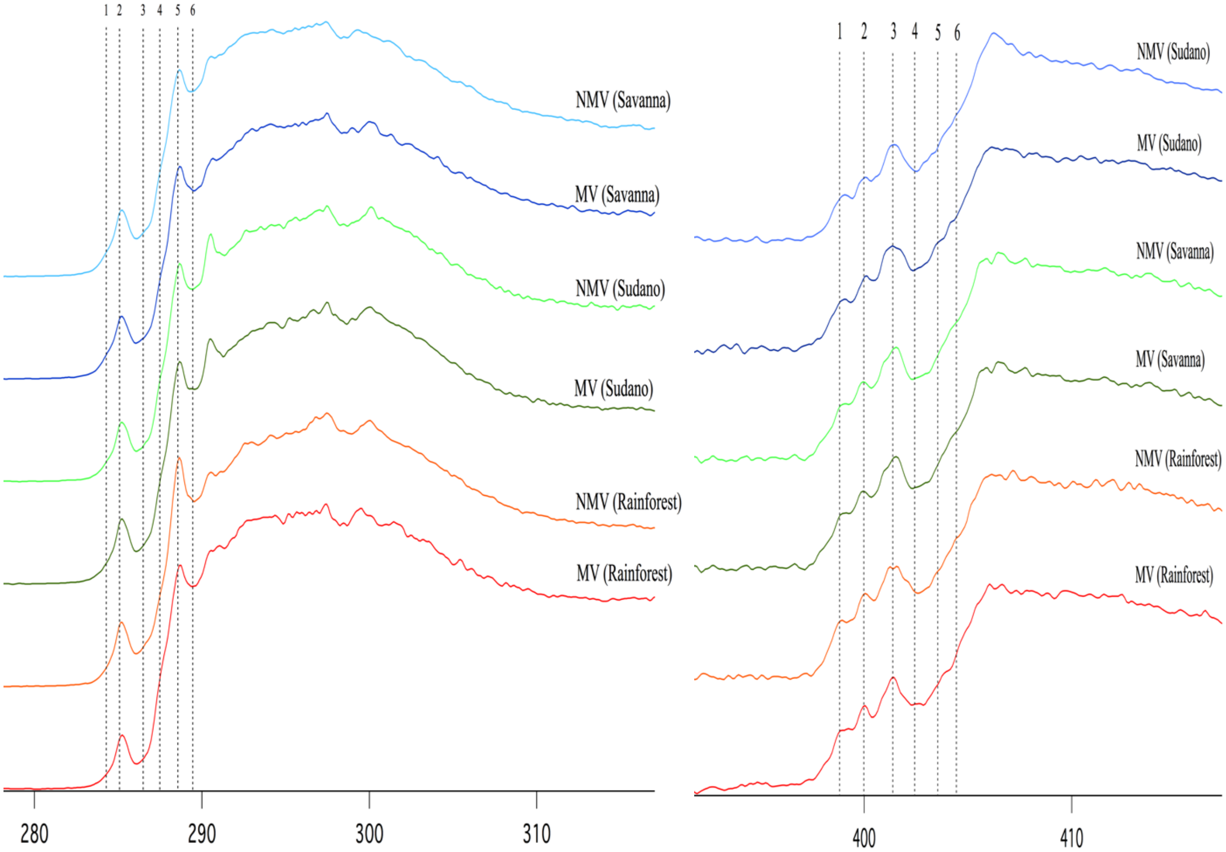


Figure 6: Carbon (a) and Nitrogen (b) K-edge XANES spectra of soil samples from MV and NMV treatments. The ecoregions are indicated in the parenthesis. 1- unsaturated-C, 2- aromatic-C, 3 – phenols, 4 - aliphatic-C, 5 - carboxylic-C, and 6 – polysaccharides. The N K-edge spectra showed the presence of 1- pryidines, 2- pyrizines, 3- amides, 4- pyrrazoles, 5- nitroaromatic-N, and 6- aromatic amines

XAS results can be used with non-metric multidimensional scaling (NMMS) to better understand how spectral features change with treatment (MV vs. NMV) or with ecoregion. Results from NMMS analysis are shown in Figure 7.

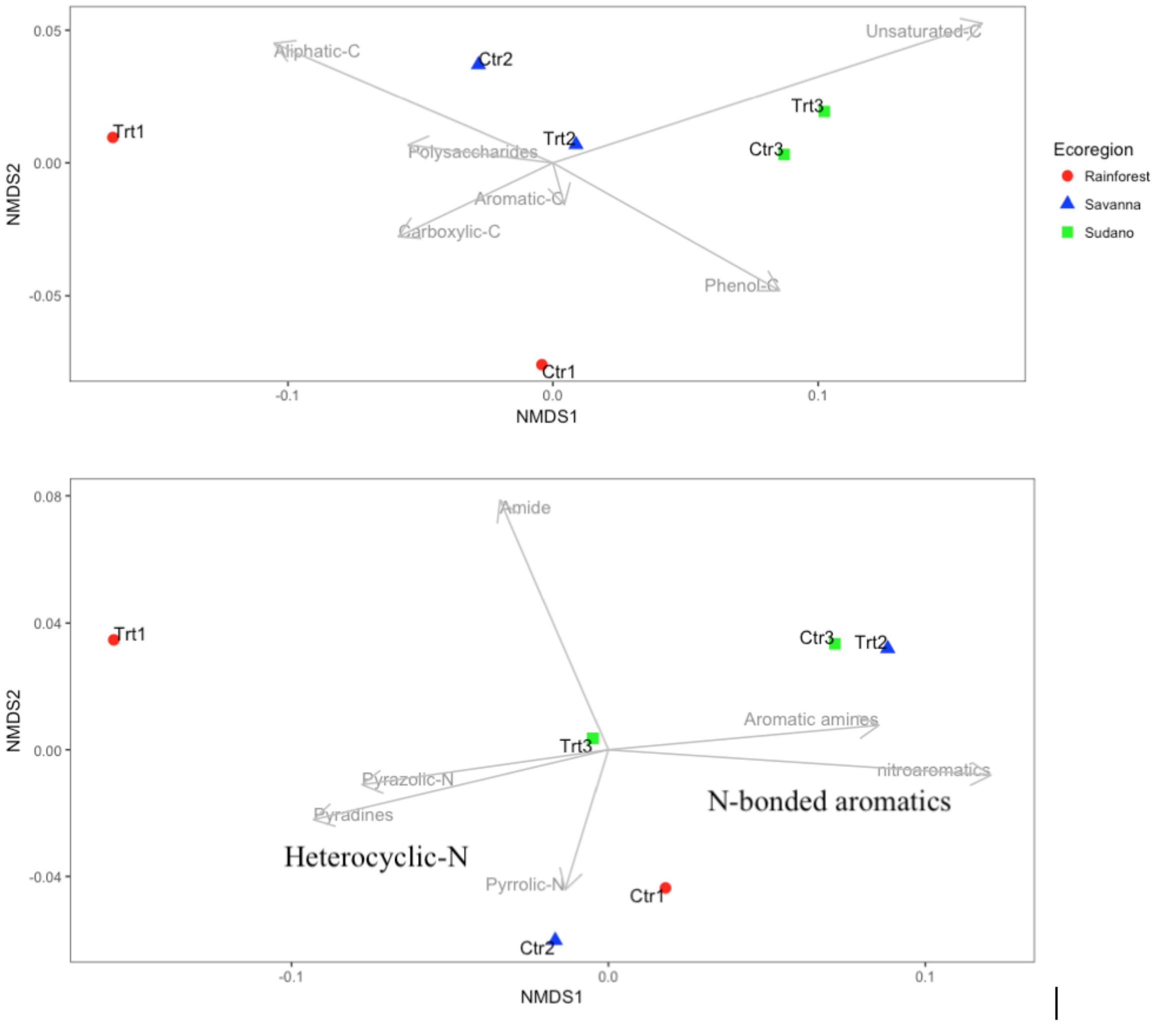


Figure 7: Non-metric multidimensional scaling (NMDS) of C (top) and N (bottom) K-edge XANES features for MV and NMV treatments in different ecoregions.

For carbon, samples clustered based on their eco-regions rather than treatment, indicating that most of the variability in C XANES spectra of the samples could be explained based on the differences in environmental factors outside of MicroVeg. Moreover, the samples receiving MV and NMV treatments were generally positioned close to each other within the ordination plot, indicating that the C functional group composition did not differ significantly among MV and NMV treatments. In the Rainforest eco-region (consisting of Ctr1 and Trt1), the MV treatment had higher abundance of polysaccharides and aliphatic-C compared to the NMV treatment. Polysaccharides are the easily decomposable C forms and are derived from leafy crop residues rich in cellulose and hemicellulose; higher abundance of polysaccharides may be related to the higher plant productivity leading to higher amount of plant inputs into the soil. These results provide direct evidence that the MV recommendations are not leading to higher degree of short-term (one to two-year) SOM mineralization and instead increased plant productivity in MV sites may provide soils with increased SOC inputs.

For nitrogen, the correlation vectors representing different N functional groups clustered such that amide-N appeared in the upper half of the ordination plot, heterocyclic-N compounds (including pyrazolic-N, pyridines, and pyrrolic-N) appeared in the lower left quadrant, and the N-bonded aromatic compounds (including nitroaromatics, and aromatic amines) appeared in the lower right quadrant. The MV treatments separated into the upper half of ordination plot, thus indicating higher abundance of amide-N in the MV compared to NMV treatments. The NMV sites (Ctr1 and Ctr2) appeared in the lower half of the ordination plot and were associated with pyrrolic-N. Amide-N is the dominant form of organic N in soils, is primarily found in peptides and proteins, and represents the proteinaceous compounds that have not been structurally altered by microbial activity. In contrast, pyrroles are the degradation products of proteins formed through microbial activity and are considered to be a potential indicator of degree of microbial metabolism.

In summary, the goal of this research was to determine the tangible benefits and identify any potential costs to soil health obtained using the MicroVeg agronomic recommendations. MicroVeg practices increased Tete yields by an average of 39 % compared to local practices due to a combination of fertilizer placement, seeding densities, and harvest intervals. **Not only did these agronomic improvements lead to higher yields, but they also decreased financial pressures and limited ecological impacts by reducing the amount of fertilizer purchased and lost to waste.** Soil chemical analysis showed a trend where MV soils had lower total nutrient levels than NMV soils. This decrease in total nutrient levels for MicroVeg soils is likely from a combination of higher yields and lower clay and silt content in those specific samples. In contrast to total levels, XANES analysis showed MicroVeg recommendations did not affect the degree of mineralization of SOC as indicated by the similar C speciation of MV and NMV sites within the same eco-regions. Additionally, N K-edge XANES analysis indicated that the microbial degradation of supplemental N may be slower at the fields following MicroVeg recommendations, as indicated by abundance of labile N forms, such as amide-N, and lack of mineralized N forms, such as pyrroles, compared to the control sites.

More generally, utilizing tools like GIS and XANES to assess the success and sustainability of agronomic recommendations in development research has potential to close the gap between potential and realized yields. With GIS there is potential to make more accurate agronomic recommendations based on properties such as soil texture, elevation, and precipitation for large geographical areas without adding additional research sites and expense. Using advanced molecular-scale techniques such as XANES, we can make adjustments to management practices to effect speciation and turnover times of nutrients in soils.

Peer-reviewed publications in review, accepted, or published:

- Olaleye, A.G, G.O. Kar, and D. Peak. In internal revision. “Molecular-scale studies of P speciation and transformation in microdose fertilized vegetable production systems in Nigeria and Benin Republic”. To be submitted to *Nutrient Cycling in Agroecosystems*.
- Procyshen, T., G.S. Dhillon, P.I. Akponipke, D. Oyedele, C. Adebooye, D.Natcher, C. Minielly, G.O. Kar, and D Peak. (in review) Innovative Approaches to Scaling up Indigenous Vegetable Production and Utilization in West Africa. *Journal of Environmental Quality*.
- Ouattara, B., S.J.B. Taonda, A. Traoré, I. Sermé, F. Lompo, M.P. Sédogo, André Bationo, S. Koala, and D. Peak. 2018. Use of an inventory credit system called warrantage to combat rural poverty and hunger in the semi-arid area of Burkina Faso. *Journal of Agriculture and Sustainability.* Accepted Oct 21, 2017.
- Natcher, D., E. Bachmann, S.N. Kulshreshtha, M.N. Baco, J. Pittman, and D. Peak. In review. “Transitions in Cooperative Labour and the Constraints to the Adoption and Scaling-Up of Labour Intensive Agricultural Technologies” *Canadian Journal of Development Studies.*
- Adams, A.T., J.J. Schoenau, and D. Peak. In review. “Fertilizer microdosing in sub-Saharan west Africa: Current state and future research needs” Geoderma Regional
- Minielly, C.M.' Natcher, D, Zeng, W, and D. Peak. 2018. “Scaling Up Research Using GIS and WebGIS Spatial Tools: Case Study” in review for special MicroVeg issue of *Acta Horticulturae (Accepted)*